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ORIGINAL RESEARCH

PREDICTION OF FUNCTIONAL MOVEMENT SCREEN™ PERFORMANCE FROM LOWER EXTREMITY RANGE OF MOTION AND CORE TESTS

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ABSTRACT

Background: There are varied reports in the literature regarding the association of the Functional Movement Screen™ (FMS™) with injury. The FMS™ has been correlated with hamstring range of motion and plank hold times; however, limited research is available on the predictability of lower extremity range of motion (ROM) and core function on FMS™ performance.

Purpose/Hypotheses: The purpose of this study was to examine whether active lower extremity ROM measurements and core functional tests predict FMS™ performance. The authors hypothesized that lower extremity ROM and core functional tests would predict FMS™ composite score (CS) and performance on individual FMS™ fundamental movement patterns.

Study Design: Descriptive cohort study

Methods: Forty recreationally active participants had active lower extremity ROM measured, performed two core functional tests, the single leg wall sit hold (SLWS) and the repetitive single leg squat (RSLS), and performed the FMS™. Independent t tests were used to assess differences between right and left limb ROM measures and outcomes of core functional tests. Linear and ordinal logistic regressions were used to determine the best predictors of FMS™ CS and fundamental movement patterns, respectively.

Results: On the left side, reduced DF and SLWS significantly predicted lower FMS™ CS. On the right side only reduced DF significantly predicted lower FMS™ CS. Ordinal logistic regression models for the fundamental movement patterns demonstrated that reduced DF ROM was significantly associated with lower performance on deep squat. Reduced left knee extension was significantly associated with better performance in left straight leg raise; while reduced right hip flexion was significantly associated with reduced right straight leg raise. Lower SLWS was associated with reduced trunk stability performance.

Conclusions: FMS™ movement patterns were affected by lower extremity ROM and core function. Researchers should consider lower FMS™ performance as indicative of underlying issues in ROM and core function. Clinicians may consider ROM interventions and core training strategies to improve FMS™ CS.

Level of Evidence: Level 2B

Key Words: Dorsiflexion, FMS™, range of motion, Single leg wall sit

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INTRODUCTION

The Functional Movement Screen™ (FMS™) is a clinical screening tool used to assess seven fundamental movement patterns.[1] Summing the scores from each of the fundamental movement patterns creates the FMS™ composite score (CS). The FMS™ CS has been associated with injury risk in some studies,[2–5] but not others.[6–9] Additionally, researchers have suggested that injury history affects FMS™ movement pattern score[10] and when injury history was combined with FMS™ CS of less than 14, Division I and club sport athletes participating in a variety of sports demonstrated a 15 times increased injury risk.[11] Further, asymmetrical performance in fundamental movement patterns that are scored separately on the right and left limb have been predictive of injury risk;[7] the combination of scoring below 14 on the FMS™ CS and asymmetrical performance in fundamental movement patterns was highly specific (87%) for injury occurrence in American football.[12] Therefore, it is important to investigate the body mechanics that may affect the FMS™ as this area has not been studied extensively[13] and may contribute to the discrepancy in injury risk.

The FMS™ purports to assess coordination of functional movements,[1] which may be related to core function. Recent studies on firefighters[14] and children[15] suggested that core muscle endurance, measured via a plank test, was significantly correlated with FMS™ CS. However, McGill's trunk muscle endurance tests were not associated with FMS™ CS in recreational athletes.[16] The McGill trunk muscle endurance tests, with the exception of the extension position, have been significantly, positively correlated with the repetitive single leg squat;[16] this finding may suggest that it is necessary to isometrically contract the trunk muscles to stabilize the upper body during the dynamic repetitive single leg squat. The single leg wall sit test has been suggested to identify athletes with rapid fatigue of lumbopelvic, hip and lower extremity muscles.[17] Further, reduced neuromuscular control of core musculature is related to lower extremity injury.[18] The single leg wall sit test has been used as a measure of lower extremity stability, and when combining the single leg wall sit test, a core endurance test, with a large number of football games played, high Oswestry Disability Index, and low trunk-flexion hold time as injury predictors, researchers suggest that core stability is important in injury prevention.[17]

In Coast Guard cadets, the FMS™ CS demonstrated moderate accuracy in injury prediction (sensitivity: 60.3%, specificity: 61.4%) in females, but low accuracy in injury prediction in males (sensitivity: 55.2%, specificity: 48.8%).[19] This difference in findings between males and females may be related to FMS™ performance differences due to documented differences in flexibility.[20] Further, males and females perform differently on the FMS™.[10,21,22] A six week yoga intervention improved trunk flexibility and FMS™ performance,[23] suggesting that improved flexibility may improve FMS™ performance. Further, superior performance on the FMS™ has been associated with increased hamstring flexibility in a sample of, primarily male, military cadets;[24] however, the role of flexibility in other lower extremity joint motions has not been established. Therefore, understanding the association between lower extremity active range of motion (ROM), in addition to core function, with FMS™ score may improve the interpretation of and intervention for specific scoring. The purpose of this study was to examine whether active lower extremity ROM measurements and core functional tests predict FMS™ performance. The first hypothesis was that lower extremity ROM and core function would predict FMS™ CS. The second hypothesis was that lower extremity ROM and core function would predict performance on the all FMS™ fundamental movement patterns except shoulder mobility.

METHODS

Study Design

This study was a cross sectional cohort design. The predictor variables included dorsiflexion, knee flexion and extension, hip flexion and extension active range of motion, single leg wall sit hold, and repetitive single leg squat test. The criterion variables were FMS™ CS and six of seven (shoulder mobility was not included in this part of the analysis) fundamental movement patterns of the FMS™.

Participants

A total of 40 participants (Table 1) volunteered to participate in this study. To be included in this study, all

Table 1. *The distribution and demographics of male and female recreational athletes*

	N	Age (yr ± SD)	Weight (kg ± SD)	Height (m ± SD)
Female	24	23.2 ± 2.4	64.8 ± 9.7	1.7 ± 0.1
Male	16	24.0 ± 2.7	82.4 ± 10.9	1.8 ± 0.1
Total	40	24.0 ± 2.5	71.8 ± 13.4	1.7 ± 0.1

participants had to be between the ages of 18 and 30 and recreationally active, which was defined as participating in physical activity of at least 30 minutes per day on at least two days per week. Participants were excluded if they reported any current injury that limited daily activity or if they answered "yes" to any question on the Physical Activities Readiness Questionnaire (PAR-Q).[25] This study was approved by the Institutional Review Boards at Daemen College and Northern Arizona University. All participants reviewed and signed an informed consent form before any data collection was initiated.

Procedures

All participants began the data collection by warming up on a stationary bike at a self-selected pace for five minutes. Next, lower extremity range of motion was measured starting with ankle dorsiflexion, which was measured with the weight bearing lunge.[26] The weight bearing lunge was used as it is a more functional position than a non-weight bearing measurement. To perform the weight bearing lunge, the participant stood 10 cm away from a wall with their great toe at the 10 cm mark of a tape measure affixed to the floor. The participant was asked to assume a lunge position and try to touch their knee to the wall. The participant was instructed to keep their heel in contact with the ground while performing this movement. If the participant was able to touch their knee to the wall they moved back one centimeter and repeated the same movement. This was repeated until the participant reached a distance at which they were unable to touch their knee to the wall without lifting their heel. In the event that the participant lifted their heel while touching their knee to the wall, the participant then slid forward one millimeter and continued this movement until a point was reached where the participant could touch their knee to the wall without their heel rising up off the ground. Once that point was established, an inclinometer (Fabrication Enterprises INC, White Plains, New York 10602 U.S.A.) was placed at a point 15 cm below the tibial tuberosity to measure the angle of the tibia in relation to the ground. This method has been shown to have good inter- (ICC = 0.97) and intra-rater (ICC = 0.97 to 0.98) reliability.[26]

Following the weight bearing lunge all participants had lower extremity active ROM measured in the following order using standard positioning and a goniometer: knee flexion (supine); knee extension (90/90 Active Knee Extension Test); hip flexion (supine); hip extension (prone). For knee flexion, the participant actively slid one heel toward as far as possible towards their buttock. For knee extension, the participant held onto the back of their thigh to maintain 90° hip flexion while actively extending the knee as far as possible in this position. For hip flexion, the participant was supine on the table with both knees bent with feet flat on table and they actively flexed one hip as much as they could, bringing their knee as close to their chest as possible. For hip extension, the participant was instructed to keep their trunk stabilized while simultaneously lifting their leg up toward the ceiling, keeping their knee extended the entire time. Three ROM measurements were obtained for each joint motion and the average was used for analysis.

Participants then completed two single leg core functional tests bilaterally: single leg wall sit hold (SLWS) and repetitive single leg squat (RSLS). The SLWS was performed bi-laterally and required the participant to sit for as long as possible with their back against a wall in a position of 90° knee and hip flexion; the time began when one leg (the participant was free to choose which leg they started with first) was lifted from the ground (Figure 1). The RSLS required the participant to perform repetitive single leg squats using the Dynamic Trendelenburg Test, (one repetition every six seconds) reaching an estimated 60° knee flexion and 65° hip flexion, while maintaining less than 10° hip adduction/abduction and less than 10° knee varus/valgus,[27] until they could no longer complete the task correctly; the number of squats was recorded (Figure 2).[16] Both the SLWS and the RSLS were explained and demonstrated to the participants before performing these tests.

Figure 1. *This is the test position for the Single Leg Wall Sit Hold. Participants were asked to hold this position for as long as possible.*

The seven fundamental movement patterns of the FMS™ were performed in the standard order: deep squat, hurdle step, inline lunge, shoulder mobility, straight leg raise, trunk stability, and rotary stability; and clearing tests were performed as indicated.[1] The movements were scored using an ordinal scale of (3-0) with a 3 representing ideal movement without compensation, a 2 representing ability to perform the movement with compensation, and a 1 representing inability to perform the movement; while a 0 was reserved for pain with movement pattern or a positive clearing test.[1] The FMS™ CS was calculated by summing scores from the seven movements, and in the case of a movement pattern that was scored on both the right and left side the lower of the two performances was used in the calculation of the FMS™ CS which has a maximum score of 21.

Statistical Analyses

Demographic data were calculated and are presented as means $\pm$ SD (Table 1). Predictor data were checked for outliers; a value that was 1.5 times less than the 25th percentile or 1.5 times greater than the 75th percentile was considered an outlier. Independent t-tests were used to assess differences between right and left limb in all ROM measures and the results of the core functional tests (Table 2). Linear and ordinal logistic regressions were used to determine the best predictors of FMS™ CS and six of the fundamental movement patterns (shoulder mobility was not predicted from the lower extremity range of motion or core tests), respectively. Data analysis

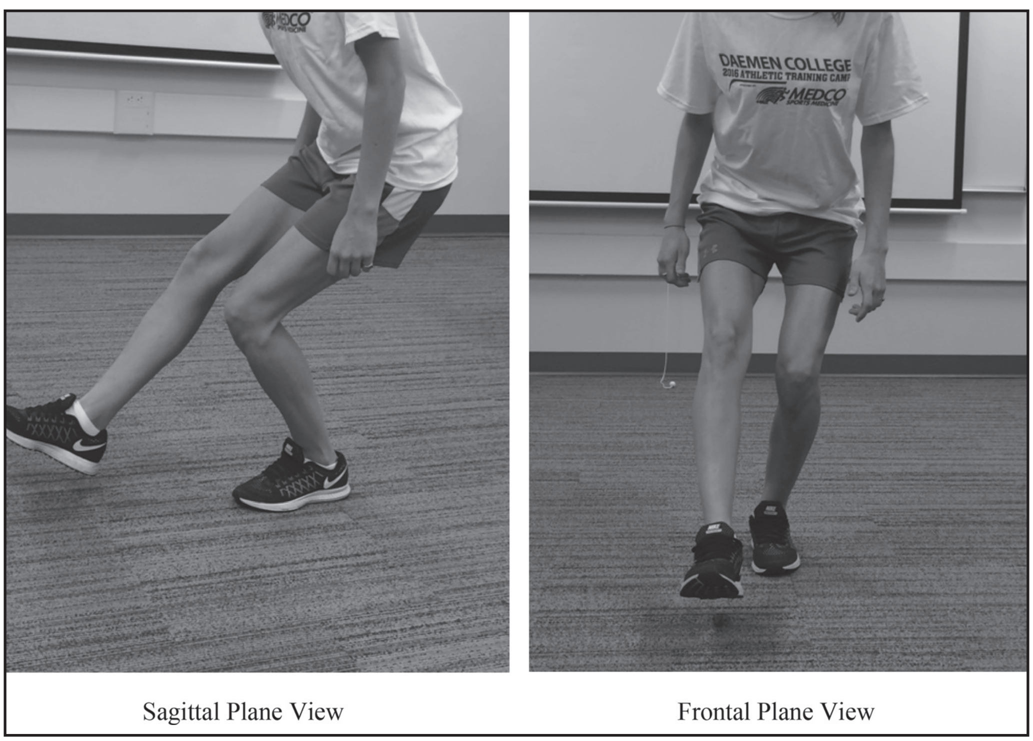

Figure 2. *This is the lower test position for the Repetitive Single Leg Squat. Participants started in single leg stance then were asked to reach this lower test position repeatedly until failure.*

Table 2. *Means [Standard Deviations (SD)] between left and right limb core tests and ROM, and p-values for statistical analysis (n = 37)*

	SLWS (sec)	RSLS (reps)	DF (°)	KEXT (°)	KFLEX (°)	HEXT (°)	HFLEX (°)
MeanL (SD)	23.38 (14.78)	22.22 (12.03)	47.78 (9.10)	20.06 (12.07)	135.61 (11.97)	15.48 (6.16)	120.07 (13.70)
MeanR (SD)	26.44 (17.22)	25.76 (17.96)	47.57 (8.65)	20.24 (11.17)	135.83 (12.25)	17.19 (6.61)	119.08 (13.37)
p-value	0.04	0.12	0.76	0.82	0.65	0.02	0.33

MeanL = mean for left limb; MeanR = mean for right limb; SLWS = single leg wall sit; RSLS = repetitive single leg squat; DF = dorsiflexion; KEXT= knee extension; KFLEX= knee flexion; HEXT = hip extension; HFLEX= hip flexion

was completed in SPSS v.20 (IBM, Armork, NY) and SAS 9.4 (SAS Institute, Inc. Cary, NC). The sample for this study included 40 participants; therefore, it was sufficient for estimation of regression coefficients as two participants per predictor has been found to provide adequate estimation in regression.[28] For the FMS™ CS dependent variables, linear regression, with forward selection, was used with an initial alpha of 0.25, and all predictors were simultaneously entered into the model. Only those predictive of performance were entered into the final prediction equation; the alpha level was set at 0.05 to calculate the R^2 for the regression model. Similar methods were utilized for the six FMS™ fundamental movement patterns as the dependent variables. Because each fundamental movement pattern is measured on an ordinal scale, ordinal logistic regression with forward selection was used. Pseudo R^2 and odds ratios were used to assess prediction.

RESULTS

The mean FMS™ CS score for all participants was 14.86 $\pm$ 2.43. The means and standard deviations for the SLWS and the RSLS and the active range of motion tests can be found in Table 2. There were significant differences between right and left limb in SLWS and hip extension (Table 2). Therefore, two separate regression models were developed; one for right predictors and one for left predictors for each criterion variable. After outliers were removed, 37 data points remained for analysis and indicated, on the left side, that reduced DF and SLWS significantly predicted lower FMS™ CS ($R^2 = 0.39$; $p < 0.001$). On the right side only reduced DF significantly predicted lower FMS™ CS ($R^2 = 0.27$; $p = 0.001$).

Ordinal logistic regression models for the movement patterns demonstrated that reduced left and right DF ROM was significantly associated with lower performance in deep squat (Table 3). Reduced left knee extension was significantly associated with better performance in left straight leg raise; while reduced right hip flexion was significantly associated with reduced right straight leg raise. Lower right and left SLWS was associated with reduced trunk stability performance.

DISCUSSION

The purpose of this study was to predict FMS™ performance based on lower extremity ROM and core

Table 3. *Significant ordinal logistic regression predictors for individual FMS™ fundamental movement patterns*

	Left SLWS OR [95% CI] Pseudo R^2	Right SLWS OR [95% CI] Pseudo R^2	Left DF OR [95% CI] Pseudo R^2	Right DF OR [95% CI] Pseudo R^2	Left KE OR [95% CI] Pseudo R^2	Right HF OR [95% CI] Pseudo R^2
Deep Squat	-----	-----	0.92 [0.85-0.98] 0.86	OR=0.92 [0.85-0.99] 0.78	-----	-----
Right Straight Leg Raise	-----	-----	-----	-----		0.95 [0.90-1.00] 0.85
Left Straight Leg Raise	-----	-----	-----	-----	1.11 [1.04-1.18] 0.85	-----
Trunk Stability	0.92 [0.88-0.98] 0.91	0.94 [0.90-0.98] 0.91	-----	-----	-----	-----

OR = Odds Ratio; 95% CI = 95% Confidence Interval function. It appears that some lower extremity ROM and core function deficits lead to diminished performance in FMS™ CS and some FMS™ fundamental movement patterns. This may suggest that injury risk might be affected by lower extremity ROM and/or core function, which could be manifested as poor FMS™ performance.

The first hypothesis was that lower extremity ROM and core function would predict FMS™ CS. This was partially supported in that reduced ankle dorsiflexion ROM and SLWS resulted in lower FMS™ CS. This is an interesting finding as a previous report indicated that participants with worse deep squat performance also had lower FMS™ CS performance and the deep squat and the FMS™ CS were positively and significantly correlated with one another.[29] Further, ankle dorsiflexion is one predictor of squat depth in males and females.[30] The results of this current study, combined with previous results, suggest that dorsiflexion ROM affects FMS™ CS.

The SLWS also predicted FMS™ performance such that decreased SLWS hold time resulted in decreased FMS™ CS. This was only seen on the left side regression model, which may be a result of the significantly lower performance of the SLWS hold time on the left limb compared to the right limb. Wall squat training has been demonstrated to increase transverse abdominis and internal oblique muscle thickness suggesting that this exercise may impact core muscle function.[31] The findings of this study may suggest that those with decreased SLWS hold times had inefficient performance of core muscles, which impacted FMS™ CS performance. Because the SLWS hold has been described as a predictor of lower extremity and core injury,[17] it is possible that previous studies demonstrating the FMS™ CS can predict injury risk[2–5] were really demonstrating that injury risk was associated with core muscle function rather than FMS™ CS. The findings of reduced dorsiflexion ROM and SLWS test performance predicting FMS™ performance may further support the questions in the literature surrounding the validity of using the FMS™ CS as a single construct[32] for injury predictability.[33,34]

The second hypothesis was that lower extremity ROM and core function would predict performance on the six FMS™ fundamental movement patterns assessed in this study. This was supported in the prediction of several movement patterns: deep squat, active straight leg raise (ASLR), and trunk stability. Reduced DF ROM and SLWS resulted in worse performance in the deep squat. This finding supports previous research that dorsiflexion ROM was significantly associated with anterior reach in the Star Excursion Balance Test (SEBT),[35] which is very similar to motion required by the deep squat, where anterior tibial translation on a fixed foot is necessary to complete both movements. Dorsiflexion ROM was found to explain 28% of the variance in performance of the anterior reach of the SEBT.[35] It would stand to reason that ankle dorsiflexion is a major contributor to deep squat performance as the compensation for inability to perform the deep squat with the feet flat on the floor (to score a "3") is to place something under the heels, which shortens the gastrocnemius/soleus muscles and reduces stress on the Achilles tendon.

Reduced right hip flexion resulted in reduced ASLR on the right side; while reduced left knee extension was associated with improved ASLR on the left side. The former of the two may seem intuitive as hip flexion is an integral part of the active straight leg raise fundamental movement. The latter of reduced left knee extension being associated with improved ASLR is a bit more counterintuitive. It is important to note that the active knee extension ROM test used in this study was the 90/90 active knee extension test. In the 90/90 active knee extension test the hip is placed in 90 degrees of hip flexion before there is an attempt to extend the knee.

To be successful in the ALSR fundamental movement the participant needs to flex their hip (while maintaining knee extension and ankle dorsiflexion) so that their lateral malleolus moves beyond a point that is half way between the ASIS and the medial femoral condyle (this position is roughly mid-thigh); the contralateral limb must remain flat against the ground in full extension without any internal or external hip rotation. This is different from the 90/90 active straight leg test as the participant is first placed in 90 degree of hip flexion and 90 degrees of knee flexion; the participant is then asked to extend their knee as far as possible. Therefore, it is likely that these two tests were not measuring the same lower extremity ROM.

The addition of ankle dorsiflexion during the straight leg raise limits hip flexion by approximately 10°.[36] Thus, the requirement of ankle dorsiflexion during the ASLR may affect performance by causing distal tensioning of the sciatic nerve;[36] therefore, hamstring length may not be the sole contributor to successful performance of the ASLR. Further, there is a negative correlation between the ASLR and the active knee extension test, which is suggested to be related to an inability to keep the knee fully extended at the end range of hip flexion[37] (or the final test position of the ASLR of the FMS™). Lastly, the ASLR is likely affected by lumbar spine stability in the transverse plane;[38] while the 90/90 active knee extension test is affected by pelvic tilt.[39] These findings suggest that, while the core is likely involved in successful performance of both the ASLR and the 90/90 active knee extension test, the function of core stability may be different between these two tests. Thus, it is possible, in the current study, that the reduced left knee extension association with improved ASLR on the left side and the reduced right hip flexion resulting in reduced active straight leg raise on the right side may have been related to differences in core function rather than range of motion.

In this study reduced SLWS hold time was associated with reduced trunk stability performance. The trunk stability fundamental movement was developed to test stabilization of the core in the sagittal plane during the closed chain activity of a symmetrical push up.[40] Poor performance on the trunk stability fundamental movement is evidence for inefficient stabilization of the trunk or core muscles,[40] while wall squats appear to be a means to train abdominal core muscles.[31] Therefore, it seems reasonable that reduced SLWS hold time would predict lower performance during the trunk stability fundamental movement.

While this study is the first to simultaneously evaluate the impact of lower extremity ROM and core function on FMS™ performance there are a few limitations. We did not measure limb dominance; however, reduced left compared to right SLWS and hip extension ROM may indicate that these two variables are affected by dominance. Additionally, this study was performed on recreational athletes limiting external validity to other populations. It is worth noting that dorsiflexion range of motion did not predict inline lunge or hurdle step performance in this study. It is assumed that dorsiflexion range of motion is an important component of both of these fundamental movement patterns. Therefore, it is imperative that researchers continue to evaluate the biomechanical basis of the fundamental movement patterns so as to elucidate underlying mechanisms before implementing interventions to improve FMS™ performance. Finally, while there were significant regression models in this study, only 30-40% of the variance in FMS™ CS performance was able to be explained by individual factors. This suggests that the FMS™ CS, while influenced by dorsiflexion range of motion and/or SLWS hold, is certainly impacted by other factors.

CONCLUSIONS

The results of this study suggest that FMS™ movement patterns are affected by lower extremity ROM and core function. Thus, injury risk may be affected by lower extremity ROM and/or core function, as these appear to affect FMS™ CS and some of the fundamental movement patterns. Researchers should consider evaluating bilateral lower extremity ROM, additional measures of core function, and limb dominance in relation to the FMS™ in order to further examine implications for injury risk and targeted injury prevention intervention programs based on more comprehensive findings.

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